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Analysis of Exhaust Emissions from Gasoline Powered Vehicles in a Sub-urban Indian Town

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Abstract

Production of 2-wheelers and 3-wheelers vehicle has been expanding rapidly over the past several years, especially in the urbanized areas of Asia. These vehicles emit substantial quantities of pollutants such as hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM). These pollutants have significant adverse health effects and deteriorate environmental quality. Presented in this paper are results of experimental study carried out to investigate the 2-wheeler emissions (CO_2, CO, NO_x, and HC) by onboard measurement method at cold start conditions, in a sub-urban area- Roorkee. Total number of hundred 2-wheelers vehicles randomly selected relatively between the 1990-2010 model years at various places. According to survey, average mileage of vehicle at the instrumentation time is 45,968 km with a maximum of 158995 km and minimum of 10,389 km. Due to the very large emissions on CO_2 compare to other gases, CO_2 emissions are projected from 2000-01 to 2030-31. In projection two scenarios were discussed here first is business as usual scenario in which 2010-11, 2020-21 and 2030-31, CO_2 intensities of all 2-wheelers modes were assumed to remain at 2000-01 levels. Second scenario was efficiency gain, where CO_2 intensities of modal were assumed to decreases at the rate of 1% and 3% per year up to the year 2030-31.

Keywords: Exhaust emission, gasoline powered vehicles, emission factor, air pollutants, CO_2 projection.

Introduction

Air quality has reached an alarmingly high level in developing countries like India. Air pollutants arise in ambient air from automobile, power plants, boilers, industries requiring crushing and grinding such as quarry, cement etc. In Indian cities, particulate matter (PM) is a major concern and 60 out of 62 metropolitan cities have exceeded World Health Organization (WHO) standards and about 2.5 million premature deaths are caused annually due to PM exposure[1]. The major pollutant from diesel engines exhausts is Particulate matter (PM_{10})[2]. Gasoline is the main fuel used in vehicular transportation, and the use of liquefied petroleum gas (LPG) is now an alternative as low emission technology to decrease the environmental air pollution. In gasoline vehicle engines the main emissions generated are nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HC) and volatile organic compounds (VOC)[3]. Oxides of nitrogen are form in the engine when elemental nitrogen in the combustion air reacts with oxygen in the presence of heat[3]. As temperature increases the amount of NOx produced also increases, as shown in figure-2. In recent years, the major sources of air pollution problems in most urban areas are vehicle tailpipe emissions. It is critical to understand the emissions as well as to implement further emission standards to control and reduce the toxic emissions (HC, CO and NOx). At present, traditional chassis dynamometer methods are used for the determination of emission factors. Exhaust emissions, evaporative emissions, refuelling losses and crankcase losses are the sources of vehicular pollution. The exhaust and crankcase emissions account for about 70 % and 20 % of the vehicular pollution respectively, whereas evaporation from tank and carburetor accounts for the rest of the part of pollution percentage[4]. Pollutants emitted by petrol engines and diesel engines are similar but may vary in proportion due to difference in the mode of operation of vehicular engines[5, 6]. CRRI conducted a study that petrol cars emit 49.61 kg of total pollutants/100 km, followed by buses and trucks (38.05 kg), 3-wheelers (35.79 kg), 2-wheelers, (27.29 kg) and diesel cars (3.21 kg)[7]. But the proportion of CO in the total emission is highest in patrol cars at 80.62 %, followed by 3-wheelers, (71.32 %), 2-wheelers (62.29 %), diesel cars (34.26 %), and buses and trucks (33.37 %)[8].There are about 900 million vehicles (excluding 2-wheelers) worldwide that emit more than 26 percent of GHG emissions[9]. A significant differences found in measured vehicle exhaust emissions for the same vehicle under similar road conditions on a single route due to individual driving styles[10, 11]. The fuel-based emission factors (g/kgfuel) varied much less than the time- and distance-based emission factors (g/s and g/km) with instantaneous speed[12]. Vehicle exhaust emissions are highest during acceleration events followed by cruise, deceleration and idle events[13, 14]. Road-based traffic volume in India will increase from 3079 billion passenger-kilometers in 2000-01 to 12546 billion passenger-kilometers in 2030-31[14]. This analysis focuses on estimation of

Emission Factor (EF) of tailpipe emissions gases (CO, CO_2, NOx and HC) under Cold- Start as well as no load condition of selected 2- wheeler fueled by gasoline, by onboard measurement method in Roorkee City. Cold- Start emission of vehicle is much higher than the Warm Start; because some time is required to warm-up the engine, so emissions of unburnt gases are much higher. A study design procedure was developed for onboard tailpipe emissions measurement systems for selected vehicles fueled by gasoline.

Material and Methods

Experimental Work: In this analysis AVL Di Gag 444 was used for the measurement of on-board exhaust emission. The AVL Di Gas 444 system, consists mainly of a power supply unit (Battery cabal to connect the 12 V battery, AC adapter to connect to the mains voltage 100- 240 V), Exhaust gas Probe 300mm, connect to enclosed 1.2 m hose to the gas house connection at the rear of the AVL DiGas 444, RPM Pick- up and other accessories. The purpose of the AVL DiGas 444 is to measure the relative volumes of certain gaseous constituents such as carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon, oxygen (O_2), and nitric oxide (NO) in the exhaust gases of the motor vehicles, engine speed and engine oil temperature can also be measured.

The study was conducted in Roorkee City at various places (NH-58) during November, 2010 to April, 2011, using total hundred 2-wheelers vehicles from a randomly selected population of owner-drivers, including 65 motor-cycles, 25 scooters, 7 scooty and 3 mopeds. Map of study area of research work is shown in figure-1.

Figure-1
Map of study area of research work

Vehicles used in the study were relatively new (1990-2011 model year) like Bajaj, Mahindra, Hero Honda, Yamaha, LML. During analysis some more information also collected about the vehicles as model, vehicle number, year of registration, fuel used, average distance travelled (per day), mileage, average speed and last maintenance date of the vehicle. According to survey, average mileage of vehicle at the instrumentation time is 45,968 km. with a maximum of 158995 km and minimum of 10,389 km.

Estimation of emission factors for various pollutants was estimated on the basis of equation 1.

$$C_xH_y + a(O_2 + 3.76N_2) \rightarrow bC_6H_{14} + cNO + dCO + eCO_2 + fO_2 + gH_2O + hN_2 \quad (1)$$

Where b = HC Concentration (ppm)/1000000, c = NOx Concentration (ppm)/1000000, d = CO Concentration (%)/100, e = CO_2 Concentration (%)/100, f = O_2 Concentration (%)/100

$$h = 1 - b - c - d - e - f \quad (2)$$

$$a = (c + 2h)/(2 * 3.76) \quad (3)$$

$$g = 2a - c - d - 2e - 2f \quad (4)$$

$$x = 6b + d + e \quad (5)$$

$$y = 14b + 2g \quad (6)$$

Exhaust Molar Mass, Instantaneous Fuel Flow Rate, Air to Fuel Ratio, Mass Air Flow, Emissions and Emission factor were estimated on the basis of following equations.

$$M_{exh} = 86.12b + 30.02c + 28.01d + 44.01e + 32.00f + 18.02g + 28.01h \quad (7)$$

$$F_f = (0.24 frpm)(A/F) \quad (8)$$

$$(A/F) = (4.76 * 28.97A)/(12.0x + 1.01y) \quad (9)$$

$$M_{af} = F_f * (A/F) \quad (10)$$

$$E(g/s) = Q * M_Q * (M_{af} + F_f)/M_{exh} \quad (11)$$

$$EF(g/kgFuel) = E(g/s) * 1000/F_f \quad (12)$$

$$EF(g/km) = E(g/s) * 1000/V \quad (13)$$

$$EF(g/Kw.h) = E(g/s) * 1000/P \quad (14)$$

Where M_{exh}= Exhaust molar mass, F_f =Instantaneous fuel flow rate, A/F =Air to fuel ratio, M_{af} =Mass air flow, E =Emissions, EF =Emission factor, Q = b, c, d, e or f depending on the associated pollutant, M_{af} = Mass Air flow, M_Q = Molecular weight of the associated pollutant, E (g/s) = the associate pollutant mass emission rate, V= Instantaneous vehicle speed, P = Instantaneous vehicle tractive power.

The three terms of emission factor are g/kw.h, g/km and g/kgFuel. The expressions of tail-pipe emission factor as g/kw.h and g/km are strongly correlated with vehicle tractive power and speed respectively. However the expression of tail-pipe emission factors as g/kgFuel is relatively independent of vehicle power and speed. Plots of emissions versus temperature are shown in figure-2. The emission factor of moped obtained with the help of above equations is very high compare to other 2-Wheelers, the cause behind that is very poor maintenance of moped and also the very old mode year of moped. Whereas tail-pipe emission factor of scooty obtained is very less compare to others model because model year of scooty is new also the very good maintenance of scooty. Emission factors (HC, NO, CO, CO_2) calculated for bike scooter, scooty and moped are given in the table 1 and represented by the graphs in figure-3. The yearly emission also estimated on the basis of total 2-Wheelers registered each year in the Roorkee from 2001-09 as shown in table 2.

Table-1
Emission Factor of 2-Wheelers

S.NO.	2 -Wheelers	EF(g/KgFuel) HC	EF (g/KgFuel), NO	EF (g/KgFuel), CO	EF(g/KgFuel), CO_2
1	Bike	10.740	0.018	16.028	51.996
2	Scooter	5.210	0.007	11.859	42.979
3	Scooty	3.319	0.024	15.450	60.180
4	Moped	91.720	0.236	88.989	124.115

Table-2
2- Wheelers Yearly Emissions in Roorkee City

Year	Registered 2-Wheelers	HC Emissions (Gg)	NOx Emissions (Gg)	CO Emissions (Gg)	CO_2 Emissions (Gg)
2001	822	13.61	0.52	167.35	329.27
2002	969	16.04	0.62	197.27	388.16
2003	1215	20.11	0.78	247.35	486.70
2004	1334	22.08	0.85	271.58	534.37
2005	1621	26.83	1.03	330.01	649.33
2006	1743	28.85	1.11	354.85	698.20
2007	2039	33.75	1.30	415.11	816.77
2008	2036	33.70	1.30	414.50	815.57
2009	1962	32.47	1.25	399.43	785.93

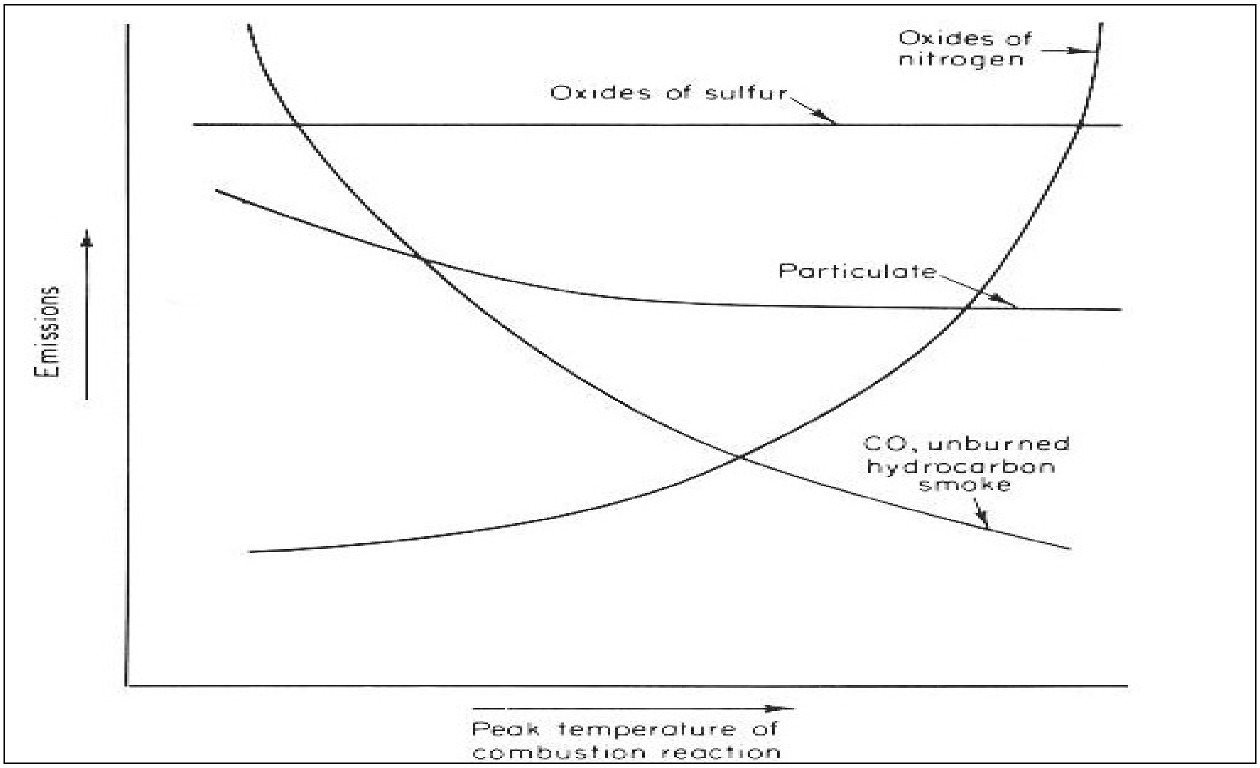

Figure-2
Plots of Emissions versus Temperature

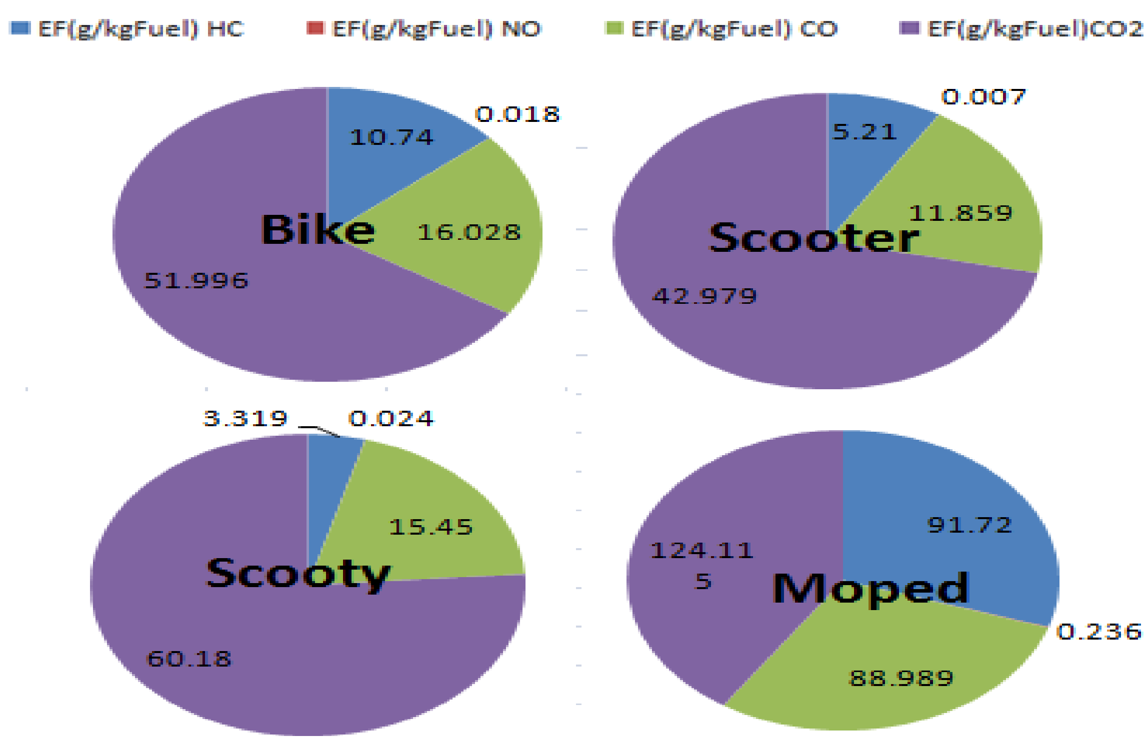

Figure-3
Emission factors of HC, NO,CO and CO_2 for various vehicles

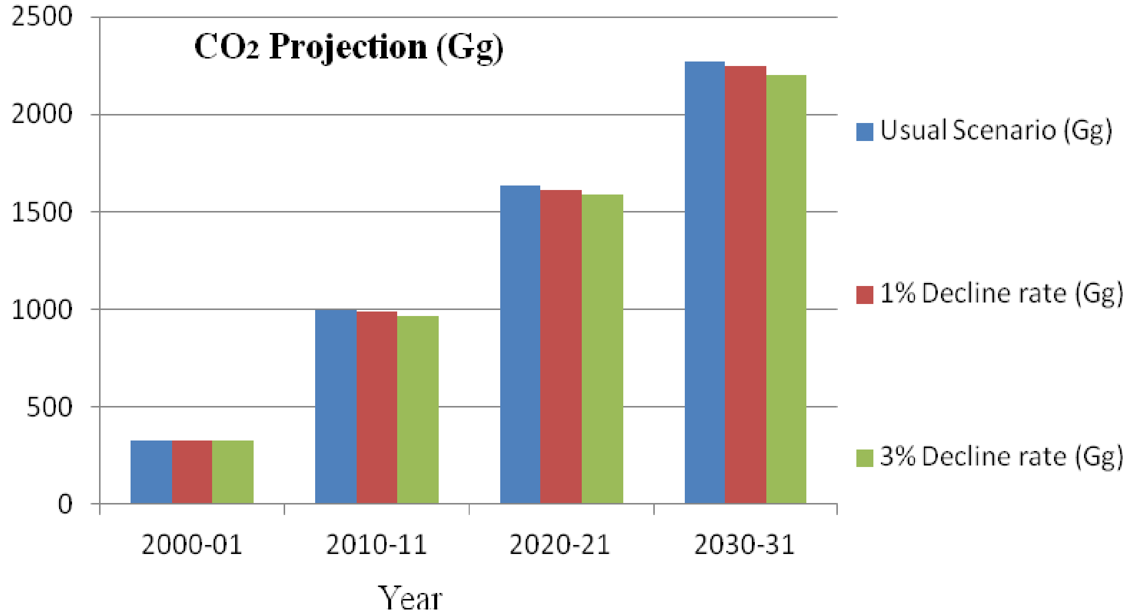

Figure-4
Projections of CO_2 emissions in usual and declined scenario

Results and Discussion

The emission factor of HC found in the case of Bike, Scooter, Scooty and Moped are 10.74, 5.21, 3.319 and 91.72 (g/KgFuel) respectively. Emission Factor of NO in the case of Bike, Scooter, Scooty and moped are 0.018, 0.007, 0.024 and 0.236 (g/KgFuel) respectively. Emission Factor obtained of CO in the case of Bike, Scooter, Scooty and moped are 16.028, 11.859, 15.45 and 89.989 (g/km) respectively. Emission Factor obtained of CO_2 in the case of Bike, Scooter, Scooty and moped are 51.996, 42.979, 60.18 and 124.115 (g/KgFuel) respectively. Total emissions of the registered vehicles are also estimated with the help of above emission factor for the years 2001-2009 as shown in table-2. Due to the exponential growth in the number of registered 2-wheelers, the result indicates that emission of exhaust gases at ideal condition is rising rapidly with the years. It have been observed that the emissions of gases at cold start condition is higher than the estimated emissions because presence of old age vehicle in the City and the vehicles coming from outside the city also contribute to the increase in emissions. Based on the CO_2 emission of the 2-Wheelers, CO_2 emission can be computed from 2000-01 to 2030- 31 by assuming as usual scenarios or decline rate per year. The projection of CO_2 in cold-start condition by assuming as usual scenarios in 2000-01 and decline rate of 1% or 3% are shown in figure-4. CO_2 emissions are projected to increase from 329.27 Gg in 2000-01 to 995.53 Gg in 2010-11, 1632.67 Gg in 2020-21, and 2269.65 Gg in 2030-31 by assuming as usual scenario. When 1% per year reduction in CO_2 emission of Cold- Start condition is assumed, CO_2 emission of the sector will virtually be same from 2000-01 to 2030-31. When 3% per year reduction in CO2 emission of Cold Start condition is assumed to the year 2030-31, CO_2 emission is projected to be 2205.56 Gg, around 222.51 Gg less than that in the as usual scenario

Conclusion

Due to the exponential growth in the number of registered 2-wheelers, the result indicates that emission of exhaust gases at ideal condition is rising rapidly with the years. Total emissions of the registered vehicles are also estimated with the help of above emission factor for the years 2001-2009 It have been observed that the emissions of gases at cold start condition is higher than the estimated emissions because presence of old age vehicle in the City and the vehicles coming from outside the city also contribute to the increase in emissions. CO_2 emissions are projected to increase from 329.27 Gg in 2000-01 to 995.53 Gg in 2010-11, 1632.67 Gg in 2020-21, and 2269.65 Gg in 2030-31 by assuming as usual scenario. When 1% and 3% per year reduction in CO_2 emission of Cold- Start condition are assumed, CO_2 emission of the sector will virtually be same from 2000-01 to 2030-31 and CO_2 emission during the year 2030-31 is projected to be 2205.56 Gg respectively. If reduction rate is assume to be 3% per year in CO_2 emission of all modes, which is more valuable than the reduction rate of 1% per year and CO_2 emission is projected to increase by 6-fold of three decades in a span.

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